(Re) making matter: design and selection

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> The notion of complete understanding controlling action is an ideal in the clouds, grotesquely at variance with practical life (Whitehead, 1956, 114-115)

Introduction

Hannah Arendt opens her major work, *The Human Condition* (1958), with an evocative meditation on the launch and orbit of the Sputnik rocket. She suggests that the success of the Sputnik shows:

> That men everywhere are by no means slow to catch up and adjust to scientific discoveries and technical developments, but that, on the contrary, they have outsped them by decades. Here, as in other respects, science has realised and affirmed what men anticipated in dreams that were neither wild nor idle. (p. 1)

For Arendt, science and culture are intimately interwoven. Science is 'anticipated in dreams'; in science-fiction writing, film and vernacular culture. This dreaming provides both the rationale for experimentation and technical development, and the cultural and cognitive frames in which to situate emerging technologies. Arendt evokes something of Benjamin's sense of the dream-state (see Buck-Morss 1989) in which the imaginative and the material are complexly wrapped in the dynamic process of dreaming. Arendt's placement of the Sputnik's orbit in the wider context of popular dreams of space travel and extraterrestrialism also addresses the temporal development of new science and the emergence of new technologies such as nanotechnology, in which 'dreams' become 'reality'. For Arendt this dreaming provides the discursive and ideological context in which such developments are positioned. New technologies are firmly rooted in, and yet challenge and potentially transform, 'the human condition'.

Recently, the philosopher Jean-Pierre Dupuy (2005) has used Arendt's notion of the 'human condition' in a provocative call for a 'philosophical foundation of nanoethics'. Following Arendt, he suggests that 'men dream science before doing it and that these dreams … have a causal effect on the world and transform the human condition' (p. 6). His use of Arendt's notion of the human condition – and her socio-political understanding of science and technology – allow Dupuy to develop a powerful case for a non-consequentialist 'nano-ethics'. In contrast to existing teleological frameworks in which ethical analysis is framed simply as a response to the consequences of specific 'techniques'(Luhmann 1992) – Dupuy re-directs attention to the transformative potential of new technologies. Dupuy suggests that ethical analysis of new and emerging technologies should not only encompass their technical specificities but also the wider socio-political framing. That is ethical analysis should not simply focus on restricted analyses of individual scientific techniques, but rather on the deontological and normative challenge posed by the potential transformations in the human condition.

In this paper I build on and extend Dupuy's account by developing what might be called a 'non- consequentialist' politics of nanotechnology. That is, I attempt to develop a political rationale for the consideration of the normative and deontological dimensions of nanotechnologies. Despite the lively characterisations of relationship between society and new technologies in contemporary fiction writing, cinema and cultural studies, contemporary political debates concerning competing visions of the relationship between technology and society are typically limited to arguments about very specific technical questions. For example, in recent technological controversies concerning GM foods and civil nuclear power, political debate largely centred on questions of safety and the veracity of official risk assessment methodologies (Jasanoff 2005; Kearnes *et al.* 2006; Wynne 1982). There is typically very little space in such discussion for normative questioning of the way the social, political and economic assumptions are built into contemporary technological imperatives. Nor is there is there space to consider the potentially transformative dimensions of new technologies outside narrow debates around risk, safety and control.

Here I focus particularly on widely articulated notions of nanotechnology as enabling, and depending upon, 'control over structure of matter', and the ability to precisely manipulate matter at the atomic scale. This vision of atomic manufacture – from the bottom up – once associated with radical and speculative possibilities of 'molecular machinery', has become a mainstream vision of fabricating nanostructures 'by design'(Kearnes, Macnaghten & Wilsdon 2006; Roco 1999). Whilst this goal has much social, cultural and moral resonance – particularly connotations of the control, the creation of life and the technologisation of nature – its rhetorical scope is not matched by the more provisional efforts of contemporary nanoscience. Such control, it seems, is more difficult to achieve than might be imagined.

This distinction between the dreams and vision of nanotechnology, and the reality of contemporary nanoscience, mirrors an almost perpetual battle to lay claim to the ‘real science’ of emerging technology – the so called ‘truth behind the nanotechnology buzz’ (Berube 2006). Central to Dupuy’s approach is the contention that nanotechnology is embedded within a set of future-oriented socio-cultural dreams and scenarios that imagine its possibilities and foretell of its potentially transformative effects (see also Brown and Michael 2003). Accordingly, Dupuy suggests that ‘existing efforts in nanoethics … take extreme care to distinguish what they deem to be serious science from what everyone refers to as “science fiction”’ (p. 6).

Similarly, Macphee (2006) suggests that ‘contemporary assessments of technology are characterised by a failure to think the impact of technology beyond notions of reproduction and intensification, so they tend to envisage the political consequences of technology in terms of static repetition, generating dystopian scenarios of disempowerment and loss of agency’ (p. 65). Discussion and analysis of the ‘social implications’ of nanotechnology has tended to mirror this process, with debate centring on areas of societal and ethical concern including; the possible toxicological effects of new nanomaterials, social, political and ethical debates about the role of nanotechnology in enhancing (human) life, improving surveillance systems and political control, widening the gap between rich and poor and possible environmental effects.[i] Visions of nanotechnology as enabling control over the structure of matter, for example, are represented as evidence for the increasing technologisation of ‘life itself’. As such nanotechnology is simply cast as an intensification of existing processes of technologisation.

This is the dilemma for consequentialist accounts in which implications of new technologies are seen to emanate only from ‘the science’. Not only does this create an awkward dependence on scientists to articulate the social, political and ethical implications of their own work, but more pragmatically Dupuy suggests ‘what constitutes [serious science] varies one report to another’ (p. 6). This attempt to uncover the ‘truth behind the hype’ suggests a broader schism between theoretical accounts of nanotechnology possibilities and their material actualisation in contemporary nanoscience.

Dupuy's ethical account is, therefore, inextricably future oriented through his suggestion that ethical analysis focus on the transformative *potential* of nanotechnologies.[ii] Similarly, for Arendt, politics is about a certain form of temporality and action – about creativity and newness. That is, her politics is based in the future – in the transformations possible to the human condition. Her meditation on the orbit of the Sputnik speaks not simply of technology as evidence of existing political stratifications. Rather, technology both enables and potentially transforms the human condition. The complex negotiation between dreams and realities of technological futures is an active political space in which such futures are *actively* worked out in the present, determining future social and political arrangements. By widening the frame of analysis and assessment of nanotechnology of Dupuy insists that questions of justice, fairness and transformations in the human conditions be addressed in the present. Similary, in their provocative call for a form of 'upstream politics' of nanotechnology Wilsdon and Willis (2004) suggest that in place of questions of safety and risk, normative questions such as:

> Why this technology? Why not another? Who needs it? Who is controlling it? Who benefits from it? Can they be trusted? What will it mean for me and my family? Will it improve the environment? What will it mean for people in the developing world? (p. 28)

be addressed in the early stages the development of a technology. Rather than simply read-off the social implications of nanotechnology Wilsdon and Willis suggest that the inbuilt political, economic, and normative framings of nanotechnology be addressed in its very development.

In concert with both Dupuy and Wilsdon and Willis I suggest that this spatio-temporal disparity between programmatic visions of nanotechnology and their articulation in nanoscience is precisely the space for a normative politics of nanotechnology. However, in describing a nonconsequentialist politics of nanotechnology I depart from Dupuy's notion of temporality. Drawing on both Henri Bergson and William James – who both share a certain 'commitment to continuity' – I suggest the disjuncture between the visions and realities of nanoscience is not simply a temporal disparity between what is possible now and what will be possible in the future. Rather this disparity describes a rather more symptomatic temporal contingency in technology itself – what Bergson terms 'the virtual' (see also Luhmann 1992). 'The future' is, strictly speaking, unknowable and yet by positing a continuum between the present and the future – in which the future is a product of individuation and differentiation – it is possible to construct a normative critique of nanotechnology. The non-consequentialist politics I develop here, therefore attempts to address normative dimensions of nanotechnology articulation in the present through a humble acknowledgement of our own ignorance in relation to the future (Luhmann 1992)

Nanotechnology Dreams

Nanotechnology is a field that is in flux. Though often ascribed to Feynman's (1960) lecture 'There's plenty of room at the bottom', the word nanotechnology itself is young, being initially coined by Taniguchi in 1974. Its constitution as a field is largely the product of recently initiated government sponsored networks of coordinated of research and innovation activities – such as the US National Nanotechnology Initiative, or nanotechnology research funding initiatives of the European Commission. Nanotechnology also displays the classic symptoms of a technological field in its early development in which there is a clear mismatch between the (often) hyperbolic promises made about its potentially liberating and transformative possibilities and the seemingly more mundane and provisional advances made in laboratory settings (Rip 2006). The key, therefore, to opening up a political account of nanotechnology is this relationship between the dreams of nanotechnology and their manifestation and permutation in contemporary research and development.

Whereas Arendt's account is vaguely populist – suggesting that science simply gives extended expression to a form of vernacular dreaming – Marcus (1995) describes the dream-quality of new technology in much more politicised terms as *technoscientific imaginaries*. Marcus suggests that tacitly held and deeply social assumptions shape the development of new science and technology. New technologies – such as nanotechnology – are imagined as solving current problems, creating wealth and prosperity, and bettering the human condition. This tacit dreaming is particularly evident in the strategic roadmapping and foresighting initiatives that attempt to anticipate and shape the development of nanotechnology. A number of such ‘roadmaps’ have recently been published, including a *Technology Roadmap for Productive Nanosystems,* a *Chemical Industry R&D Roadmap for Nanomaterials by Design,* a *Technology Roadmap for Nanoelectronics,* and even a roadmap for *Nanotechnology in the Forest Product Industry* (European Commission 2004; Foresight Institute 2005; Forest Product Laboratory 2005; Vision 2020 Technology Partnership 2003). These roadmaps – which are typically sponsored and strategically published by Governments and industry associations – offer scenarios that *will* be enabled by nanotechnology and as goals to be achieved. They attempt to give coherence to the development of nanotechnologies and to lever discursive attention for a range of specific ends – for example to emphasise the importance of nano*electronics* over and above other applications of nanoscience and technology. Such imaginaries are ways of ‘marshalling’ the future through the deployment of hope, expectation and anticipation (Anderson this volume; Brown and Michael 2003; Van Lente 1993). They also serve to shape the field, advocating for greater research coordination and funding on sub-fields of particular promise.[iii]

Similarly, public discourse and commentary concerning nanotechnology is dominated by speculative lists of existing and possible future applications of nanotechnology. For example, Forbes magazine publishes an annual list of ‘top nano products’. The 2005 list included nanotechnology-based footwarmers, a washable bed mattress which uses nanoparticles to create an ‘semi-impervious layer that traps fluids and particles so they can be washed away’, and the 3M dental adhesive that utilises a ‘silica nanofiller technology that forms a stronger bond to tooth enamel’ (www.forbes.com). Alternatively Roco and Bainbridge’s (2002) National Science Foundation report *Converging Technologies for Improved Performance* provides an almost limitless list of possibilities enabled by advances at the nanoscale. This list of potential applications includes: more durable human bodies, efficient weapons systems and ubiquitous real-time information systems.

In addition to predicted applications of nanotechnology other tacit visions signal the socio-political expectations of the *value* of nanotechnology. For example, Doubleday (this volume) suggests nanotechnology represents an 'intensification of concern in science policy with the application of knowledge for economic growth'. The potential economic impact of nano-related products is typically cast as 'revolutionary'. For example, US nano-policy documents speak of nanotechnology as 'leading to the next industrial revolution' (NSTC 2000a) and current estimates of the potential value of future nanotechnology industries range anywhere from the billions to the trillions (Department of Trade and Industry 2002). Doubleday continues by suggesting that built into this expectation is the further expectation that strategic funding and infrastructure support will maximise the profitability of UK nanotechnology innovations. He suggests that this is manifested in an 'imperative to produce useful knowledge [which] has shaped the practice of academic nanoscience over the last decade'.

Similarly Kearnes, Macnaghten and Wilsdon (2006) outline a series of 'programmatic imaginaries' of nanotechnology that operate as meta-level discourses and as key drivers in the development of nanotechnology. For example, nanotechnology is described as an extension of the 'miniaturisation imperative' and as perpetuating the inexorable drive toward miniaturisation of electronic circuits and data storage. Also nanotechnology is represented as a new kind of science which is both interdisciplinary and 'socially robust'. Both Bennett and Sarewitz (2006) and Rip (2006) describe the way in which this discourse of social robustness is intimately tied to the expectation that nanotechnology represents an opportunity to 'learn from the mistakes' of past technology controversies by building social intelligence and research into the development of the technology itself (see also Macnaghten *et al.* 2005).

Discourses of Control

Such discourses are enabled by, and dependent upon, the foundational conviction that nanotechnology represents a new scientific paradigm based on the ability to precisely control and manipulate matter at the atomic and molecular scales. The vision of nanotechnology as both enabling and depending upon the precise control over the structure of matter is best exemplified by the former HP researcher Jamie Dinkelacker (2002), who claimed that: 'Total (or near total) control over the structure of matter will intrinsically revolutionise our lives. No Aspect of our daily living – let alone other technologies – will remain untouched' (p. 2). This phrase – 'control over the structure of matter' – is a symbol of the sheer promise and transformative possibility of nanotechnology. Despite its obviously hyperbolic tone, the imperative to gain such control has become a paradigmatic goal for much nanotechnology research. This goal has become *the* default objective for current research through which to realise the wider transformative possibilities of nanotechnology (Kearnes *et al.* 2006; Kearnes, Macnaghten & Wilsdon 2006). Roco (1999) signals this basic programmatic goal for nanoscale research, by defining nanotechnology as:

> Concerned with development and utilization of structures and devices with organizational features at the intermediate scale between individual molecules and about 100 nm where novel properties occur as compared to bulk materials. It implies the capability to build up tailored nanostructures and devices for given functions by control at the atomic and molecular levels. (pp. 1-2)

For Roco, nanotechnology is defined as a capability to create tailored structures at the nanoscale, based on precise control and manipulation of matter at this scale. The key for Roco is the injection of human-derived 'function' at the nanoscale through the production of tailored nanostructures and materials. Though advances in nanoscience have been successful in producing novel materials and fabrication processes, this degree of atomic control remains elusive. As such the quest to achieve control at the nanoscale represents, for Roco, *the* underlying and unifying project of contemporary nanoscience research. Roco suggests that once such control is achieved it be possible to create tailored nanostructures with desired shapes, patterns and architectures.

Visions of control over the structure of matter are both theoretical and pragmatic, suggesting that such control is logically possible and constitutes the 'next step' in developing functional nanotechnologies and materials. The theoretical vision of the possibilities for precise control of the atomic scale is motivated by what might be termed a biological turn in physics and a materialist turn in biology. Primary in this context is Erwin Schrödinger's (1944) essay *What is Life? The Physical Aspect of the Living Cell* which implies a physicalist understanding of life by suggesting that biological processes may be explained physically. In this work – which prefigures later developments in systems theory – Schrödinger explains the origin of life in physical terms, through recourse to theoretical physics. Indeed, the opening lines of Schrödinger's 'little book' – a quote from Spinoza's *Ethics* – 'Homo liber nulla de re minus quam de morte cogitat; et ejus sapientia non mortis sed vitae meditatio est[iv]' signal the intention to deploy the physical discipline of physics to explain life itself, and particularly the emergence of self-ordering systems. Accordingly he asks: 'How can events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?' (p. 3). Schrödinger answers this question by suggesting that life is implicitly atomistic. He argues that biological processes are controlled and determined by characteristics of their atomic constituents. For example, he suggests that:

> The unfolding of events in the life cycle of an organism exhibits an admirable regularity and orderliness, unrivalled by anything we meet with in inanimate matter. We find it controlled by a supremely well-ordered group of atoms, which represent only a very small fraction of the sum total in every cell. (p. 27)

For Schrödinger living cells are physical. All things – and therefore biological process and life itself – are absolutely divisible into atoms and molecules. Schrödinger's vision of life also signals the importance of the notion of control. He suggested that, though complex, the emergence of ordered, biological life is controlled by atomic constituents of such processes. Through this vision of absolute divisibility it becomes possible to technologically manipulate life itself through the precise design control of this atomic base (Mody 2006). Schrödinger's suggestion that biological life is accomplished through the selective control over the movement of atoms and molecules demonstrates the possibility of similar human designed processes.

The second theoretical reference informing discourses of the precise control over the structure of matter is what might be termed a 'biological turn' in theoretical physics and mathematics, particularly in the work of von Neumann. Von Neumann's theory of automata – a mathematical model of self-reproducing systems – represents a form of computational determinism. His theory suggest the possibility that naturally occurring self-reproducing systems might be recreated through appropriate algorithms (von Neumann 1961). The goal, for von Neumann, is to 'apply the philosophy underlying natural automata to artificial automata' (1966, 71). As such he prefigures the machinic imitation of 'natural automata' by suggesting that it is possible to create a machine which recreates itself modelled on biological examples. Thus he compares Turing's early work in computing:

> which is a box with a finite number of states. Its outputs are modifications of another entity …The medium which is fed to the automaton and which is produced by the automaton is completely different from the automaton. In fact the automaton doesn't produce any medium at all; it merely modifies a medium which is completely different from it. (p. 74)

to a machine which is able to create copies of itself:

> There is no question of producing matter out of nothing. Rather one imagines automata which can modify objects similar to themselves, or effect syntheses by picking up parts and putting them together (p. 75, see also Cooper 1983)

For von Neumann, life is controlled by code and is essentially computable. The goal, for von Neumann, is therefore the creation of sufficiently complex computations that would model such existing natural systems.

Von Neumann and Schrödinger provide both the vision and theoretical resources for the precise manipulation and control of matter in contemporary nanoscience. For both, 'life' is the benchmark against which to compare 'human-designed' machines. Indeed both marvel at the complexity of biological systems and the ability of living machines to self-organise and self-reproduce. The key object is to recreate the functionality of living systems and the means and possibility of its technological recreation (Lehn 2002).

This theoretical account of the sheer possibility of designing functional nanosystems also provides the foundation for a more pragmatic vision in which accomplishing such control represents the logical 'next stage' in the development of nanotechnology. For example, Roco (1999) suggests that:

> The promise of nanotechnology is being realised through the confluence of advances in scientific discovery that has enabled the atomic and molecular control of material building blocks, and engineering that has provided the means to assemble and utilise these tailored building blocks for new purposes and devices. … Assembling of atoms, molecules and collections of assemblies of molecules into nanostructures with a defined function by design, under

> controlled conditions, is a critical component of nanoscale science and technology. (p. 5)

For Roco, current applications of nanoscience represent only the first stage of a broader technological program. The 'next stage' is the creation of nanostructures defined not simply by their novel properties but by their 'function' as objects of human-derived design. Control over the structure of matter is therefore represented as both a theoretical possibility, and pragmatically as the 'next stage', that must be achieved in order to accomplish the wider promise of nanotechnology.

Design and Evolution

The key terms of this vision are, therefore, design, precision and control. This discourse mirrors that of the 'fantastic voyage'[v] by suggesting that the, as yet, unexploited space of the atomic might be subject to human intentionality and engineering (Schwarz 2004). The intersection of visions of control, precision and function with broader expectations of value, and the exploitation of the nanoscale, signal the politics at stake in the development of nanotechnology (Waldby 2002). Nanotechnology represents an intensification of technological control over the atomic bases of life itself. Such visions of 'life', 'matter' and 'evolution' connect with enduring discussions of the implications of new and advanced technologies. Both Fukuyama (2002) and McKibben (2003) present a dystopian account of the technological transformation of biological life through biotechnologies. For both, such technologies represent further evidence of Heidegger's notion that modern technology is defined as a project of alienation from, and technological mastery, over nature (Heidegger 2003). Alternatively, for Rose (2001), the penetration of design and control into the atomic and material bases of life contributes to 'politics of life itself'. Rabinow and Rose (2003) situate contemporary biotechnologies as an intensification of political control over life itself and symptomatic of the broader Foucauldian thesis that 'Power … is now situated and exercised at the level of life.' (p. 1).[vi] Conceivably, nanotechnology represents a further incarnation of this politicisation of life, with an even finer grained control over the atomic bases of life. The intensification of this politics of life is further strengthened by the fact that discourses of control over the structure of matter are themselves the product of wider socio-political expectations of the value and transformative potential of such interventions. The transformation of matter at the nanoscale is therefore emblematic of this generic transformation in the operation of political power, such that molecular life is subject to control and manipulation.

Both accounts of the socio-political implications of the technologisation of 'life itself' treat such technologies simply as evidence of a wider politicisation of life. Technology figures as either producing the dystopic 'end of nature' – for Fukuyama (2002) and McKibben (2003) – or as an advanced iteration in the development of disciplinary power. Casting nanotechnology as simply an intensification of the technologisation of life is dependent on a particular notion of the temporality of technologies, in which specific nanotechnologies are situated as discrete, temporally specific achievements. Such accounts are dependent on accepting that visions of the control over the material world *will* be developed in the future. Both accounts fail to conceptualise what Ardent characterises as the active and transformative capacity of technology. The political significance is not simply that matter is – or *will be* – transformed by nanotechnology. Rather the politics of nanotechnology are constituted through the negotiation of visions and dreams of control and more provisional results of nanoscience research.

Both accounts, also ignore the material contingency inherent in the development nanotechnology and visions of control over the structure of matter. For example, visions of control operate in (at least) two ways (Bensaude-Vincent 2006). First, early speculative and futuristic accounts of nanotechnology entailed visions of the direct physical manipulation of matter. According to these accounts future nanotechnology would be characterised by nanoscale machines, factories and replicators that would create objects 'atom by atom' through the direct and precise positioning of atomic particles (Drexler 1986). The theoretical possibility suggested by both Von Neumann and Schrödinger is suggestive of a second and more active version of nanoscale control, in which processes of evolution and systems change are utilised and mimicked in the fabrication of structures and devices. Rather than directly manipulate matter atom by atom, existing chemical and biological processes are used a template for designing functional nanosystems (Jones 2004; Seeman and Belcher 2002).

The difference between both notions of control is the degree of intentionality with which matter is to be transformed. The direct manipulation of matter, atom by atom, indicates the possibility of creating fully intentional tailor-made and human-designed nanostructures. Technical discussions and debates of this vision have concerned the sheer technical feasibility of the precise manipulation of matter in this way, and have been characterised by attempts to lay claim to the scientific reality of nanotechnology and what is 'actually possible' at the nanoscale.[vii] The second account, in which 'life' is used as a template for nanotechnology, presents a more complicated and distributed vision of intentionality. Rather than directly manipulate matter, nano devices and structures would be 'created' – or grown – by using existing self-replicating systems or chemical synthesis as templates or by modelling the functionality of biological systems such as protein or DNA (Conrad 1992; Huie 2003; Lehn 2002; Rasmussen *et al.* 2004; Whitesides and Grzybowski 2002). Such creations are, therefore, not fully intentional. Rather, they are the product of a form of intentional evolution.

The suggestion that nanotechnology simply represents an intensification of contemporary biopower therefore ignores the fact that experimental systems rarely dominate their subject. Despite articulations of total control the material world the material specificity of the nanoscale necessitates forms of control over that are both contingent and provisional (Kearnes 2006).[viii] A political engagement with visions of control over the structure of matter must, therefore, attend to this inbuilt temporality. Particularly useful in this context is the pragmatist notion of 'radical empiricism' in which felt experience is expressed not as a succession of atomic instants, but rather as a continuum. William James (1909) outlines radical empiricism as a phenomenology of:

> a through-and-through union of adjacent minima of experience, of the confluence of every passing moment of concretely felt experience with its immediately next neighbours. (p. 326)

If life is cast, in this way, as immersed in a continuum of felt experience – which evades objective description – specific materialisations of life therefore represent temporal modifications rather than discrete entities. Bergson (1911 [1988]) expresses the creation of specific materialities in the context of this continuum as movement of the virtual and the actual. He suggests that Bergson:

> I enter neither into one nor into the other nor into both at once, although both, united, may give a fair imitation of the mutual interpenetration and continuity that I find at the base of my own self. … Matter divides actually what was but potentially manifold; and, in this sense, individuation is part of the work of matter, in part the result if life's own inclination. (p. 258)

The implication of both Bergson and James' 'commitment to continuity'[ix] is that technological objects are themselves immersed in a temporally specific continuum. This is particularly apparent, for example, in the histories of technology developed by Leroi-Gourhan (1943; 1945), Simondon (1964; 1992) and Stiegler (1994) in which particular technologies are regarded in evolutionary terms as material individuations, ruptures or breaks in an overall continuum of human – and non-human – experimentation. For Bergson, new technologies are a result of a form of differentiation rather than heroic creation. He replaces a notion of "realisation" with a conception of "actualisation" suggesting that technical objects are provisional achievements that might also be subject to further change and evolution (see also Deleuze 1986; 1989; 1991). Dupuy suggest that visions of nanotechnology as enabling the precise control over the structure of matter are justifiable read as ethical and normative claims upon future human social arrangements. In extending Dupuy account, I suggest that a normative politics of nanotechnology necessitates a rendering of the material and temporal ruptures that make such forms of control possible, and yet render them as inextricably provisional and contingent.

Nanotechnology as a site of 'enchantment'

In late 2004 I spent some time at the Cambridge Nanoscience Centre – talking to and observing nanoscientists – trying to unpack the societal, political and ethical dimensions of nanoscience and nanotechnology. The nanoscience centre – and others like it in London, Bristol, Manchester and Newcastle – is an attempt by the university to coordinate and centralise nanoscale research in one building with shared access to research equipment, instruments and clean rooms. It is in this building that images of futuristic nanoscience are perhaps best realised, with its collection of state-of-the-art clean rooms, open-plan office, research, and informal meeting spaces. The nanoscience centre is the also the lead partner in a larger network of nanoscience research – an Interdisciplinary Research Collaboration (IRC) between the University of Cambridge, University College London and the University of Bristol, jointly funded by four UK research councils – the EPSRC, BBSRC, MRC and the MoD. As one of the premier UK nanoscience research consortiums the IRC 'is directed at the very core of nanotechnology and as such will aim to provide an underpinning interdisciplinary activity with the general theme of fabrication and organisation of molecular structures' (Cambridge University 2001, 2).

Whilst at the Nanoscience Centre I met a young researcher – John.[x] He explained that the aim of his research was investigating techniques for the synthesis of three-dimensional nano-structures and nano wires. As such the goal of his research was to develop ways of catalysing the growth of such nanostructures so that by controlling the growth conditions he might be able to produce a reproducible method for synthesising three-dimensional nano-structures with desired shapes, patterns and morphologies.

John explained the goals of his research:

> If we can understand how structures are grown then maybe we can tailor the way we grow structures and actually grow a structure which we're looking for … The whole point is that we want to be able to control the structure, the morphology, and the size of these structures. Then [they can] self assemble into an array and then from there it has some technological relevance because you know you've got control and you can reproduce the stuff which is the main problem. (Interview with Researcher, Cambridge NanoScience Centre, 2004)

John's research is therefore concerned with the nature of certain materialities – specifically nanoscale silicon carbide. At a fundamental level John was interested in the material properties of nanoscale silicon so as to produce more reliable ways of growing desirable shapes and wires. In this way the ambition of John's research contributes to the meta-level goal of gaining control over the structure of matter. The key goal for John was to create reproducible methods for the fabrication of nanostructures with and desired shapes and patterns. His research aimed not only to investigate the nanoscale properties of silicon carbide, but rather to create specific and tailored nanoscale arrangements of silicon carbide.

However, John also explained that he primarily worked by using the existing literature on the material properties of silicon and silicon dioxide to build computer simulations of its growth and by testing these models experimentally. In his research practice, John negotiated a complex relation between theoretical simulations of the 'behaviour' of nanoscale iron and the behaviour exhibited in his experiments.

> I'm trying to develop a catalyst technique which is reproducible. So that every time I grow some nano structures I'm using the same catalysts, or I know what's happening at that fundamental level. … And so I'm trying to reproduce a way of making iron nano particles to catalyse these structures and I'm having trouble doing that. And you know I've been talking to the author of the paper and I don't know. Something's amiss somewhere but I haven't found it. It's rather frustrating. (Interview with Researcher, Cambridge NanoScience Centre, 2004)

For John, this frustration is caused by the disjuncture between his experimental results and what he had expected based on computational models and theoretical accounts. Although this ambiguity, caused by the difference between theoretical accounts and experimental results, is a generic feature of scientific practice, John's frustration speaks of a wider disparity. There is a disjuncture between the dreams of nanotechnology and the results of scientific practice (Rheinberger 1997; Stengers 1997). Though John's research is situated within a wider attempt to investigate possible fabrication techniques, the reproducibility and reliability of such techniques has proved elusive. This mismatch between the theoretical possibility of the precise manipulation of matter and more provisional results of contemporary nanoscience is a common feature of the field. For example, another researcher at Cambridge described how *a priori* assumptions of control and accuracy are moderated by actual research practice:

> Most of it is looking at what biology has done and saying right, I'll have that. So you take it out of the biological context. And sometimes they just do something that you don't expect at all. We don't have the mechanisms to predict. We can't say right I'll take this and it will do this. We're just not advanced enough in our biology. It's a horribly complex system. It is possible to achieve control, but only by trial and error. (Interview with Researcher, Cambridge NanoScience Centre, 2004)

There are many ways of interpreting this disparity. It is tempting to suggest that the disparity between discourses of control and prediction and the provisional results of nanoscience is a measure of the gap separating nanotechnology ‘dreams’ from nanotechnology ‘reality’. The notion that discourses of control and nanoscale functionality are *simply* fiction compared with *actual* nanoscience is an attractive proposition. However, for proponents of nanotechnology the difference between theory and practice is simply evidence of a temporal distinction between scientific research and technological development. They suggest that such difficulties will be overcome in time. Thus, for example, proponents of the creation of functional nano-devices and molecular machines typically employ long time horizons in predicting the emergence of such developments.[xi] Of course definitions of what ‘counts’ as (legitimate) nanoscale research is the subject of much conjecture. Opponents of the radical visions of nanoscale machines suggest that this disparity evidences a broader impossibility of creating functional nanoscale devices, and the necessity to gain broad consensus on other goals for nanoscience research.

Rheinberger (1997) captures something of the ambivalence of research practice and the mismatch between theory and results. He terms the products of the experiment ‘epistemic things’, capturing the dual quality of objects that are simultaneously conceptual and materially situated. In defining epistemic things he suggest that the results of experimental systems are: ‘shaped in and occupy an opaque intermediary space: they lie, so to speak, at the interface between the material and the conceptual side of science’ (Rheinberger 2003, 624). For Rheinberger, the indeterminacy of such objects suggests that they are objects of conjecture and argument in the development of scientific knowledge and the refinement of experimental systems. That is they are political objects. The disparity between visions of the control over the structure of matter and experimental results serves a metaphor for nanotechnology in general. Nanotechnology is a field in flux, characterised by competing claims to its ‘reality’. The movement between discursive accounts of nanotechnology and the ambivalent materialities is a movement through which different ‘realities’ of nanotechnology are produced, or ‘enacted’. As explored above, nanotechnology is the subject of an array of promises and expectation, which are ambiguously interpreted and negotiated by nanoscience researchers. Though such discourses play an important role in structuring the meta-level goals of nanotechnology research, the relationship between programmatic visions and the everyday practice of nanoscience is complicated. In this negotiation gaps and tensions emerge between structural visions of the economic and social promise of nanoscience and researchers' own experiences.

For example, in response to predictions of a nanotechnology revolution, many of the scientists interviewed were more cautious and pragmatic. One researcher at Cambridge questioned the expectations that his science should be used as an engine for innovation:

> I've no interest myself in applying the science which comes out. I'm interested to see what happens but I'm not interested in being entrepreneurial with the material... The goal as I see it is to do research and to get the results into the literature and see what other people do with it. … I mean Gordon Brown and others are perhaps trying to redefine my job to be something different and I've a lot of sympathy with that but I'm not convinced I'm necessarily the right person to be doing that. (Interview with Researcher, Cambridge NanoScience Centre, 2004)

The mismatch between visions of control and the results of contemporary nanoscience also, therefore, mirror a wider negotiation of social, political and economic discourses that structure nanoscience and technology.

Conclusion – Towards a Nano-politics

There are many ways of interpreting this disparity between programmatic visions and experimental practice. For proponents of nanotechnology this disparity evidences simply a temporal negotiation of such discourses. They suggest that control over the structure of matter will be achieved 'in the future' and that predicted social and economic impacts will therefore ensue. Dupuy interprets this future-orientation temporally as a moment for ethical analysis and assessment and also therefore for the political negotiation of the normative dimensions of such claims upon the future. Alternatively Nordmann (2006) suggests that such claims on the future are more precisely related to the politics of the present – in attempts to lay claim to the nanoscale and to create rhetorical leverage in the negotiation over the 'reality' of nanotechnology. For Nordmann, nanotechnology is spatial and is defined by an attempt to inhabit the space of the nanoscale (Nordmann 2004).

Dupuy and Nordmann therefore position political engagement with nanotechnology differently as either a temporal project of debating claims upon (future) human conditions and social arrangements *or* as a negotiation of the present conditions through which nanoscience is organised as particular set of claims upon the nanoscale. Alternatively I suggest that a normative politics of nanotechnology might rethink the very possibility of ‘laying claim’ to either the temporal or the spatial. The disparity between the ‘dreams’ and ‘reality’ of nanotechnology is not simply a distinction between science fiction and science fact, nor a question of dreams that will be realised at some future date. Rather, by adopting a radical empiricist notion of spatio-temporality – Bergson’s notion of duration – it is possible to highlight the impossibility of objectively ‘laying claim’ to either the temporality of the future or the spatiality of the nanoscale. In the same way that Bergson suggests that technological devices are not simply discrete achievements, but rather moments of individuation, the future exists as a form of differentiation.

A non-consequentalist politics of nanotechnology might therefore be cast as a way of relating to an unknowable future – an acknowledgement of what Luhmann (1992) terms an ‘ecology of ignorance’. He suggests:

> Today we can speak of the future practically only in terms of the probable or improbable, that is, in terms of a fictively secured reality. We now know that future presents will bring other things than the present future can express, and when we speak of the future we express this discrepancy by dealing only with probabilities and improbabilities (p. 95)

Given that it is only possible to speak of the future in terms of probabilities a non-consequentalist politics of nanotechnology might therefore adopt a relational spatio-temporality as an alternative stance to that of ‘laying’ claim to either the future or the nanoscale.

Whereas the possibility of creating functional nanosystems and tailored nanostrcutures is informed by notions of control and precision, this articulation is complicated by their ambivalent reception by nanoscientists. In the context of the elision between competing visions of nanotechnology, political power operates in an attempt to create coherence and consensus in an otherwise unruly field. Roadmapping, foresighting and standardisation activities utilise public policy to shape the development of nanotechnology toward prescribed ends. However these attempts to claim the future are complicated by the sheer unknowability of the future

Nanotechnology does not simply represent a further intensification of the modernist drive toward the technologisation of life and alienation from nature. Though dreams of atomic control and precision are a permutation of this narrative, nanotechnology is best described as a set of contingent technological futures. The social and political implications of nanotechnology are not simply mitigated *against*. Rather in Arendt's terms the politics of nanotechnology is an active politics of creating the future. She suggests that 'the *polis*, properly speaking, is not the city-state in its physical location; it is the organisation of the people as it arises out of acting and speaking together' (Arendt 1958 198). In the same way that Jasanoff (2003) calls for 'technologies of humility' and a re-examination of human pretensions of control over technological systems we might imagine a mode of agonistic political relation – of acting and speaking together – that adopts a similar humility in relation to the spatio-temporality of its inventions. That is, by attending to normative dimensions of nanotechnology articulation in the present we might humbly approach the contingency of our responses to the future.

Notes

[i] Recent attempts to characterise the breadth of social concern associated with nanotechnology have sought to distinguish between broader socio-political implications and narrower question of environmental and human risk associated with new nanotechnologies. Accordingly Renn and Roco (2006) distinguish two frameworks of 'risk debate' in which narrow questions of environmental toxicology would be tackled through existing risk assessment methodologies and wider social-political concerns through political debate and consensus.

[ii] My thanks to Alfred Nordmann for conversations on this point.

[iii] There has been such a proliferation of such roadmapping and foresighting activities that a critique of the possibility of 'roadmapping congestion' and lack of clarity has emerged (Smith forthcoming).

[iv] 'There is nothing over which a free man ponders less than death; his wisdom is, to meditate not on death but on life' (Spinoza Ethics, 1677 Pt IV, Prop. 67)

[v] The 1960s science fiction film in which a miniaturised submarine in injected into the scientist Jan Benes.

[vi] See also Foucault (1990).

[vii] See for example the well publicised debated between Eric Drexler and Richard Smalley: (Smalley 2001; 2003a; 2003b; Drexler 2003a; 2003b)

[viii] In this context recent geographical scholarship on matter and materiality has emphasized the significance of what Kearnes (2003) terms 'the expressive waywardness of matter' (p. 149 see also Anderson & Tolia-Kelly 2004) as an expression of material agency that escape forms of technical determination.

[ix] See Ansell-Pearson (2002) for an analysis of both James and Bergson on the notion of continuity.

[x] All names have been anonymised.

[xi] For example, Renn and Roco (2006) suggest that the development of nanotechnology can be broken into four stages or generations:

1st generation: Passive nanostructures from 2000
2nd generation: Active nanostructures from 2005
3rd generation: Integrated nanosystems from 2010
4th generation: Heterogeneous molecular nanosystems from 2015/2020.
Whilst 1st generation products are currently commercially it is claimed that 4th generation nanotechnology – truly functional devices – will be developed at some point in the future. (Foresight Institute, no date).

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